JOINT MANAGEMENT PLAN REVIEW
Ecosystem Protection – Krill Harvesting
Strategy MB-KH1
Ecological and Economic Argument

Note: This document does not yet reflect all changes made during the February 11th meeting.

In Support of a Coordinated Effort to Prohibit Krill Harvesting in the Federal Waters of the Monterey Bay National Marine Sanctuary

Purpose

As per the requirements of the National Marine Sanctuary Act (16 U.S.C. et seq., as amended by Public Law 106-513) and as stipulated in a 1992 Memorandum of Understanding between the National Ocean Service and National Marine Fisheries Service (NMFS), the Monterey Bay National Marine Sanctuary seeks to work with NMFS and the Pacific Fisheries Management Council (Council) in its effort to permanently prohibit the harvesting of krill in the federal waters within Sanctuary jurisdiction. The purpose of this document is to present the Council and NMFS with the ecological, practical, and statutory rationale for seeking this cooperative action.

Introduction

The Monterey Bay National Marine Sanctuary (MBNMS) is the largest marine protected area in the United States. Designated in 1992, the Sanctuary is a nationally recognized area of unique ecological significance and beauty. It operates under a congressional mandate to protect the resources within its jurisdiction from a broad, ecosystem based perspective. This requires consideration of a complex array of habitats, species, and interconnected processes and their relationship to human activities. Krill are a critical component of the marine ecosystem and fundamental to the trophic structure of the marine life within the Sanctuary. Studies in Monterey Bay have confirmed that krill have the highest biomass of all zooplankton grazers in the Monterey Bay upwelling system. They form a key trophic link in coastal upwelling systems between primary production and higher trophic level consumers. Most species, including humans, are only one or two trophic levels away from krill and it is the primary prey of 7 of the 10 most important nearshore commercial fishes on the central California coast. It also makes up over 90% of the diet of endangered blue and fin whales.

The two principal species of krill that exist within the Sanctuary and throughout the California current are *Euphausia pacifica* and *Thysanoessa spinifera.* However during strong El Nino times *Nycthyphon simplex* comprise a large component of krill biomass. These species are preyed upon by salmon, rockfish, squid, sardine, mackerel and flatfish. Numerous seabirds including sooty shearwaters, cassin's auklets, and common murres are also dependent on krill as forage. Reliable regional estimates of biomass and prey requirements do not exist. However, it has been estimated that krill makes up between 15 and 60 percent of the diet of commercially significant fish in ecosystems with comparable trophic structures.[1] Krill are currently not harvested within the Sanctuary, however, the potential exists for this fishery to develop in the future due to an increasing need for aquaculture feed. A krill fishery could not only severely impact the integrity of the marine ecosystem but could adversely affect commercial and recreational fisheries.

The 1996 re-authorization of the Magnuson-Stevens Act required the Secretary of Commerce to appoint an ecosystem advisory panel which developed recommendations for implementing ecosystem principles into federally created fisheries management plans. The panel has considered the numerous threats to the ecosystem posed by overfishing and has generally advocated a more risk averse policy of management. This primarily includes promoting more conservative harvest limits as well as the use of marine reserves. While these two strategies have serious political and socio-economic consequences, the prohibition of krill harvesting is a comparatively painless way for the Council and NMFS to take precautionary, ecosystem based action and meet the recommendations made by the advisory panel. The Sanctuary therefore seeks to form a partnership with NMFS and the Council to ban the harvesting of krill in the federal waters of the Sanctuary and achieve the mutual goal of effective management and protection of marine resources.

Regulatory Environment

The National Marine Sanctuary Program

The National Marine Sanctuary Program is a division of the National Ocean Service (NOS), which like NMFS, is an office under NOAA. Under the National Marine Sanctuaries Act (NMSA), NOS is responsible for protecting Sanctuary resources and facilitating multiple uses within the MBNMS that are compatible with resource

[1] Nicol, S. & Endo, Y. Krill Fisheries: Development, Management and Ecosystem Implications. Aquat. Living Resour. 12 (2) (1999) 105-120.

protection. The NMSA provides sufficient regulatory authority to accomplish these management objectives, including authority to regulate fisheries and fishing activities as necessary to address specific issues within the MBNMS. Any such regulation would be developed in cooperation with state and federal authorities, as appropriate.

The regulation of fishery resources within the MBNMS is a collaborative process, in which the Sanctuary would work with NMFS and the Council to insure that these important resources are protected. The Sanctuary may manage fishery resources within its boundaries by imposing specific regulations on certain fishing methods and gear or preventing the taking of fish when it is determined to be necessary to protect cultural sites, to protect important natural resources or to maintain biodiversity or the health and balance of the Sanctuary ecosystem. Sites that have adopted such regulations include the Monitor, Florida Keys, Fagatele Bay, Flower Garden Banks, and Gray's Reef Sanctuaries. Where the existing regulatory measures taken by the state, the Council, and NMFS are found to afford appropriate protection to Sanctuary resources, the Sanctuary achieves its objectives by working with these entities to ensure that the appropriate level of protection is maintained.

It may be determined that additional ecosystem protection regulations should be imposed in the Sanctuary, to achieve management objectives under the NMSA or for the goals and objectives of the MBNMS. In such a situation, the Sanctuary would consult with the Council, NMFS, the California Department of Fish and Game (if applicable), and the public. When appropriate, the Sanctuary may request that the relevant fishery management agency address MBNMS concerns within that agency's own statutory and regulatory context. In situations where the legal framework of that agency preclude it from adequately addressing Sanctuary objectives, then pursuant to subsection 304(a)(5) of the NMSA, the Council would be given the opportunity to prepare draft Sanctuary fishing regulations for the portion of the Sanctuary within the Exclusive Economic Zone. If the Council decides to prepare such draft regulations it is to use as guidance the national standards of section 301(a) of the Magnuson-Stevens Act to the extent those standards are consistent and compatible with the goals and objectives of the Sanctuary.

If the draft regulations are found by NOS to meet the goals and objectives of the Sanctuary and the purposes and policies of the NMSA, they will be published as Sanctuary regulations. If, however, the Council declines to make a determination as to the need for fishing regulations in the Sanctuary, makes a determination that is rejected by NOS, requests that NOS prepare the draft regulations, or does not prepare the draft regulations in a timely manner, NOS will prepare the fishing regulations. Regardless of whether the Council or NOS drafts the Sanctuary fishing regulations, NOS will be responsible for compliance with the National Environmental Policy Act, Administrative Procedure Act, and other such requirements, such as where necessary, amending the Sanctuary's designation document.

The original Designation Document and Final Environmental Impact Statement (EIS) for the Monterey Bay National Marine Sanctuary state that existing fisheries were not being regulated as part of the initial Sanctuary regime. However, the Final EIS also states that if regulatory exemptions for fishing threatens Sanctuary resources, NOS could undertake rule changes consistent with Federal procedures. This would involve the MBNMS consulting with CDFG, PFMC, and NMFS to determine an appropriate course of action. Pursuing the restriction of krill harvesting is therefore a legitimate means for the Sanctuary to both meet its mandate, and a valuable opportunity to provide its ecosystem based perspective to fisheries management. However, the National Marine Sanctuary Program recognizes that the primary regulatory authority over fisheries management resides with these agencies, and as an initial step will encourage these agencies to work with the Sanctuary to take the necessary measures.

The State of California

There is currently a ban on krill harvesting in the state of California. The bill was introduced by Assemblywoman Virginia Strom-Martin, and was aimed at "protecting the marine food web by stopping any krill fishery before it could be started in the state." The Strom-Martin bill was requested by the Pacific Coast Federation of Fishermen's Associations (PCFFA) and conservation groups after a krill fishery was established several years ago off British Columbia. This fishery is the first off the Pacific coast and has been implicated in the poor recovery of cod in the region. PCFFA and others were concerned that "fishing for this essential link in the food chain would prevent the recovery of highly valuable and threatened commercial fish." This bill prohibits the taking or landing of krill of the genus *Thysanoessa* or the genus *Euphausia* for commercial purposes until January 1, 2011. It further provides that after January 1, 2011, this commercial taking or landing is prohibited unless permitted under regulations adopted by the Fish and Game Commission.

The National Marine Fisheries Service/Pacific Fisheries Management Council

There has been no federal action considered prohibiting or limiting krill fishing in federal waters by the regional Councils or NMFS. The Council is required by the Magnuson-Stevens Act to manage fisheries pursuant to fishery management plans. There is currently no fishery within the jurisdiction of the Council and there is therefore no management plan. The absence of a plan precludes the Council from creating regulations under the Magnuson-Stevens Act, however as discussed above, it may draft and promulgate regulations under the Sanctuaries Act. The Council could also endorse the Sanctuary drafting its own regulations under the Sanctuaries Act.

Description of Potential Local Krill Fishery

The only significant current market for krill on the west coast exists in Oregon and Washington where salmon farms use krill meat to give farm raised fish their pinkish color. Most of the supply currently comes from the British Columbia fishery. However, the federal waters in the Sanctuary may soon be open to fish farming, outside the reach of the state prohibition. NMFS is currently soliciting comments on their proposed Code of Conduct for Offshore Aquaculture, which could place net pens in areas of the Sanctuary. This code was generated pursuant to the Department of Commerce's stated goal of a five hundred percent increase in the nation's aquaculture by the year 2025. These net pen raised fish will likely demand krill as feed stock and a fishery may develop around the needs of these aquaculture facilities. This may significantly increase the likelihood of a krill fishery developing within Sanctuary waters.

A krill fishery within the MBNMS would correspond to peak krill abundance and aggregation which occurs in summer and early fall. Any of the over a hundred trawling vessels at the ports associated with the Sanctuary could participate, and as other fisheries are closed down there will be an increasing number of vessels searching for viable alternatives. However, there are several key limitations that may serve to effectively exclude most local fishermen from any emerging krill fishery. Perhaps most significantly the Strom-Martin bill not only prohibits the taking of krill from state waters but it also makes landing krill in any state port illegal. Therefore, a krill fishery on the central coast would most likely consist of large factory trawlers. The factory trawlers operating in the Southern Ocean have harvested krill at a rate as high as thirty five tons in eight minutes.

A krill fishery may have serious adverse impacts on many of the local commercially important fish stocks including salmon, rockfish, sardine and squid as these species are heavily dependent on krill as a food source. The aquaculture facilities would also compete directly with the wild caught fisheries within the Sanctuary. Prohibiting this fishery now would preclude a post-hoc redistribution of effort and prevent later socio-economic impact.

Review of the Antarctic Krill Fishery

Estimates of krill abundance in the Southern Ocean suggest a sustainable krill harvest of around 150 million tons a year, 1.5 times greater than the total number of fish and shellfish harvested annually from the world's oceans. The desire to tap into this vast resource led to the birth of a commercial krill fishing in the early 1970s which has continued unabated ever since. The current catch is a little under 300,000 tons a year which although down from the peak years of the early 1980s, is still by far the largest catch in Antarctic waters. Krill are caught by large freezer trawlers and processed on board into products for human consumption, domestic animals (cattle, poultry, pigs and mink) and farmed fish. Currently only six nations are actively involved in the fishery: South Korea, Chile, Poland, Japan, Russia and the Ukraine, with the last three accounting for 96 percent of the catch.

Concern over a fishery that targets the foundation of the Antarctic trophic structure, led to the signing of a unique fishing treaty in 1981. This was the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR), designed to protect the Antarctic ecosystem from the consequences of a rapidly expanding krill fishery. CCAMLR set a limit of 1.5 million tons on the catch of krill in the South Atlantic (where almost all of the krill has been caught recently) and a limit of 390,000 tons for the Indian Ocean. These limits are much higher than the current catch levels but this is a reflection of the huge size of the resource and of the pre-emptive approach to management that CCAMLR was designed to take. Market demand has been the limiting factor since the fishery began and catch has remained at a fraction of what are considered highly precautionary limits.

While the overall take of Antarctic krill is relatively low compared to its abundance, concerns have been raised over fishing's regional effects. CCAMLR has instituted an ecosystem monitoring program to detect and record significant changes in critical components of the ecosystem. It has been assumed that it is possible to assess the effects of fishing on krill availability through some index of predator performance. Predator data has therefore been incorporated into the management scheme. Accordingly, a system to regularly record selected life history parameters of key seabird and seal populations has been in place since 1986. Despite calculations of krill yield that take into account krill and predator requirements, CCAMLR has been aware of the potential for local competition between predators and the krill fishery. On a global scale fishing mortality might remain within the limits set by management and so provide sufficient escapement for predator needs. However, on a local level mortality may be much greater and escapement too low to support predators with restricted foraging ranges, or may cause a shift in the behavior and distribution of more widely ranging species. This concern is exacerbated by the timing of the krill fishery during months where many species of breeding bird and seal predators are dependent on the resource.

It has been reported that in South Georgia seals, penguins and albatrosses are having difficulty in rearing offspring successfully as demand for krill has begun to exceed supply in some areas. Twenty years of long-term monitoring of seabirds and seals on South Georgia has revealed an increase in the frequency of years when there is insufficient krill to feed seal pups and seabird chicks. The animals did well in the 1980s while stocks of krill were abundant but demand began to exceed local supply in the 1990s. The extent to which these changes result from a decrease in the amount of krill or an increase in predator demand is uncertain. However, the similarity between the supply and demand is a new discovery and throws into question the apparent super-abundance of krill over all of the Southern Ocean. Seals and seabirds now consume such a large proportion of the krill population at South Georgia that they amplify the effects of gradual, underlying environmental changes. The discovery provides a new insight into the status of krill at South Georgia and highlights a vital need to re-examine the scales at which krill stocks are managed through CCAMLR.

The Uniquely Productive and Susceptible Waters of the Sanctuary[2]

The oceanographic and bathymetric features of the MBNMS make it uniquely susceptible to the adverse effects of krill fishing. The Monterey Submarine Canyon and local upwelling zones provide krill with a distinctive habitat that contribute to their abundance and degree of aggregation. This makes the waters within the Sanctuary a critical feeding ground for numerous forms of wildlife. These include predators like the blue whale, dense concentrations of seabirds, and commercially important fish species such as salmon and rockfish. This unique productivity is due to the coastal upwelling that occurs seasonally within the Sanctuary. Equatorward winds develop in the spring due to movements of the Aleutian low-pressure system and North Pacific high. These winds act in combination with the Coriolis force, leading to a positive curl in the wind stress that moves an Ekman layer of surface waters offshore. This draws cold, nutrient-rich deeper water to the surface that extends as a broad band of cool water 10's of kilometers along the California coast. In some regions fronts, plumes, and eddies can develop, extending >100 km. This seasonal upwelling of nutrient-rich water supports high primary production and, in turn, higher trophic levels. Studies have shown the importance of the Monterey Bay National Marine Sanctuary upwelling centers to krill abundance and that the long-term survival of many marine bird and mammal populations depend upon the summer/fall productivity of these areas of the Sanctuary.

In Monterey Bay, high levels of primary and zooplankton production are supported by springtime upwelling to the north of the Bay between Pt. Año Nuevo and Davenport. During the spring/summer upwelling season, pulses of northwest wind lasting a few days generally develop around February, supporting pulses of high primary production which lag the initiation of upwelling by 6-10 days. Depending on conditions, these pulses can

[2] Adapted from: Benson, S.R., D. A. Croll, and B. Marinovic. Whales, krill, and variability of two coastal upwelling centers. Tech. Report No. 01-1. 2001. *and* Croll, D.A., B. Marinovic, S. Benson, F.P. Chavez, N. Black, R. Temullo, B.R. Tershy. 2000. From Wind to Whales: Trophic Links in a Coastal Upwelling System. Final Report to the Monterey Bay National Marine Sanctuary, Contract No. 50ABNF500153

sporadically occur into the summer/fall season.. Krill abundance is therefore typically highest in the late spring to summer period. Physical and biological oceanographic studies in Monterey Bay have confirmed these seasonal patterns and demonstrate linkages between physical forcing, sea surface temperature, and productivity in the Bay. Moderate krill abundance has been found to exist through February, with distinct scattering layers near the surface and below 150 m. However, by March, krill backscatter is considerably reduced, and the deeper backscatter layer is no longer present. It is not until July, several months after the seasonal increase in primary production and the initiation of the summer/fall period, that krill backscatter dramatically increases. At this time both the shallow and deeper backscatter layers reappear, persist through September and begin to taper off in October. The seasonal arrival of blue whales in Monterey Bay appears to be linked to this dramatic increase in krill in July.

Data collected during the 1997/98 El Niño and 1999 La Niña events in the Monterey Bay upwelling system demonstrate the close link between upwelling and rorqual whales. In July 1997, krill abundance declined sharply in response to El Niño warming of nearshore waters. Paradoxically, this led to a dramatic increase in large whale abundance. This was due to the fact that while productivity was low in Monterey Bay during the 1997/98 El Niño, it was even further reduced in other foraging areas. Thus, the limited amount of productivity in Monterey Bay was the best foraging area available for the whales. Conversely, by May 1999, the strongest La Niña event on record brought cold nutrient-rich waters into Monterey Bay, supporting high primary production and extremely high krill abundances. However, by July 1999, krill abundance decreased sharply and whale densities declined.

The upwelling centers are not the only feature that make the Sanctuary a pelagic hotspot. The bathymetry also plays a role in the abundance and aggregation of marine life. There are several factors that may lead to the association of krill with the edge of the Monterey Bay Submarine Canyon. Krill are generally found in regions of high primary productivity. In most areas they have been studied, adult epipelagic krill such as E. pacifica and T. spinifera undergo diel migrations to depths in excess of 100 m. Along the central California coast, the continental shelf break occurs at a depth of around 100-150 m. Some of the most productive coastal waters along the California coast are found over inshore of the shelf break, downstream from upwelling centers. Topographic breaks in the shelf such as the Monterey Submarine Canyon bring water depths in excess of 1,000 m within 10 miles of shore, downstream from upwelling centers such as Pt. Ano Nuevo. These breaks provide krill that aggregate in the canyon the ability to undergo diel migrations in excess of 100 m (presumably to minimize predation in daylight hours) while remaining in the highly productive recently upwelled nearshore waters.

The current dynamics of the canyon may also help reduce energetic costs for swimming in krill during the day. Below 100 m over the continental slope off central California, the dominant current is the northward-flowing California Undercurrent. Ramp et al. (1997) found that northward currents at 100 m depth off Pt. Sur, California (approximately 60 km south, outside of Monterey Bay) were approximately five times greater than those found in the Monterey Submarine Canyon where krill were aggregated. Thus, the Monterey Submarine Canyon habitat would provide: 1) the opportunity for high energy gain during nighttime surface feeding due to its location downstream from an upwelling center; 2) a refuge from daytime predation as krill can migrate to depths in excess of 100 m in the canyon, and 3) reduced swimming energy output during daytime schooling at depth due to reduced canyon slope currents.

Whales[3]

Over the last twenty years there has been a steady increase in the abundance of large baleen whales in California waters during spring, summer and fall, with current estimates of 2200 Blue whales and nearly 1000 Humpbacks. As discussed, many prime feeding areas lie within the Sanctuary. These whales along with sei and fin whales, draw thousands of whale watchers each year, who make a substantial contribution to the local economy. Theses planktivorous behemoths consume enormous amounts of krill. Blue whales are almost completely dependent on the resource, consuming up to three metric tons per day. Sei whales eat .8 mt of krill per day and Fin whales consume 1.8 mt/day. Humpbacks in Monterey Bay switch opportunistically from krill to schooling fish such as anchovy, but on average consume 1.3 mt/day.

Ultimately, the fate of these planktivorous predators depends upon reliably available concentrations of krill in coastal upwelling centers. The distribution of blue whale sightings and krill densities and the daytime vertical distribution of whale dives and krill indicate that whale foraging effort is concentrated on dense krill schools associated with the Monterey Submarine Canyon. Schoenherr (1991) first reported the association of blue whales with the steep topography of the Canyon, and further studies have confirmed this observation. This association could result from whales directly responding to physical patterns in water temperature or currents in this region, or they may be associating indirectly via patterns in the distribution of biological resources that are directly responding to the canyon edge habitat. Water temperature and current patterns in the upper portion of the water column in Monterey Bay are most strongly influenced by upwelling north of the Bay than the canyon feature itself, so it is unlikely whales are

[3] Adapted from: Croll, D.A., B. Marinovic, S. Benson, F.P. Chavez, N. Black, R. Temullo, B.R. Tershy. 2000. From Wind to Whales: Trophic Links in a Coastal Upwelling System. Final Report to the Monterey Bay National Marine Sanctuary, Contract No. 50ABNF500153

directly associating with the canyon. Instead, whales are aggregating on the canyon edge in order to exploit dense schools of krill associated with it.

Whales dive directly down to the densest aggregations of krill between 150 and 200m on the canyon edge. Whales seek patches that are approximately two orders of magnitude greater than the densities generally available in Monterey Bay. Measurements directed at patches where whales were observed foraging within the Sanctuary, provide an estimate of the magnitude of prey densities for large rorquals. These densities are higher than both the mean (6-73 kg m-2) and maximum (154 kg m-2) densities estimated for Thysanoessa raschi and Meganyctiphanes norvegica by Simard and Lavoie (1999) using acoustics in the Gulf of St. Lawrence, an important blue whale foraging area. These values are also higher than mean values in other regions of high krill density: 2-102 g m-2 for the Scotian Shelf, North and 30-61 kg m-2 for Elephant Island, Antarctica.

How do these densities compare with prey densities observed for other zooplanktivores? Brodie et al. (1978) estimated that fin whales required prey concentrations of at least 17.5 g m-3 to meet its daily energy requirements. Although mean krill densities in Monterey Bay were much lower than this, such densities were readily available at the canyon edge. Dolphin (1987) estimated krill densities where humpback whales were foraging at 910 individuals m-3 (compared to a finding in the Sanctuary of 4,403 individuals m-3), and that minimum required densities were about 50 individuals m-3. Wishner et al. (1995) found that zooplankton densities in regions where right whales foraged in the southwestern Gulf of Maine were approximately 3 times the mean densities in the region (whale feeding densities averaged 3.1-5.9 g m-3, compared to 1.1-3.6 g m-3 where whales were not foraging). In a related study, Macaulay et al. (1995), using hydroacoustic surveys, estimated zooplankton density where right whales were foraging at 18-25 g m-3 (compared to 1-5 g m-3 where whales were not foraging).

The annual migratory movements of the blue whale likely reflect seasonal patterns in productivity in other foraging areas similar to those described for Monterey Bay. Regions with different seasonal upwelling patterns and krill species with different life history traits will show temporal differences in peak krill abundance. Due to their high total prey requirements, California blue whales likely migrate seasonally between dense, ephemeral krill patches that appear in southern/central California in the summer and fall, the Gulf of California in the winter, and the central Baja California Pacific coast in the spring. California blue whales foraging in the coastal upwelling zone seek extremely dense patches of krill aggregated on the edge of the Monterey Bay Submarine Canyon. High krill densities appear to result from the habitat provided by the proximity of the deep canyon to an upstream coastal upwelling center. Dense patches seasonally develop, lagging the seasonal increase in productivity by 3-4 months. This lag may result from the temporal development of krill spawned around the seasonal peak in primary production and the tracking of the shoreward collapse of productivity with decreased coastal upwelling.

Dependent Commercial Stocks[4]

Many commercially important species are dependent on krill as forage. However, the trophic interactions for these species are not always completely understood and the percentage of krill in a given species diet may not be quantifiable, particularly on a local level. A krill fishery within the Sanctuary could be expected to compete with the dietary needs of these species to varying extents. A description of the diet and local fishery and status of some of these species are summarized below.

Pacific Hake *(Merluccius productus)*

Pacific hake is one of the most abundant groundfish populations in the California current system. This species is caught almost exclusively in midwater trawls, in water depths of 100–500 m. In recent years, catches of Pacific hake on the central coast have been largely influenced by annual recruitment. Higher catches occur 3–4 years following strong recruitment years. Very large year-classes of Pacific hake were produced in 1980 and 1984, leading to high catches in Central California throughout most of the 1980s. Most of the landings were delivered into San Francisco ports, however, and are not reflected in the landings for ports near the MBNMS. Coastwide recruitment was average or low between 1987 and 1992, but a strong 1994 year-class is indicated from high bycatch of juveniles in recent years. Landings within the MBNMS have fluctuated over the past twenty years, declining from a high of over 9,000 lb in 1984 and followed by years with increasing trends and years with little to no commercial landing of Pacific hake.

Because of its large biomass, Pacific hake is an important predator in the California Current ecosystem, and its impact on other commercially valuable species has been the object of several studies. During a 1995 survey, the stomach contents of 377 Pacific hake were collected from waters over the outer continental shelf and upper continental slope in the Eureka area (approx. Cape Mendocino, California to Cape Blanco, Oregon). By weight, the stomach contents consisted mostly of krill (31%), flatfishes (25%), sergestid shrimp (13%), lanternfishes (13%), cannibalized Pacific hake (8%) and pink shrimp (3%). Similar to other studies, the importance of krill in the diet decreased with increasing size of Pacific hake.

[4] Adapted From: Trends in Fisheries and Fishery Resources Associated with the Monterey Bay National Marine Sanctuary From 1981–2000. R. Starr, J. Cope, L. Kerr . California Sea Grant College Program Publication No. T-046.

Market Squid (*Loligo opalescens*)

Market squid is the top commercial fishery in California by pounds landed and by value. Commercial landings of market squid for all of California in 1999 totaled nearly 200 million lb and were worth nearly 35 million dollars. From 1981–82, squid catches within the MBNMS were relatively high, with annual landings totaling more than 20 million lb but landings decreased drastically to a low of 1 million lb in 1984, a result of the 1982-83 El Niño conditions. From 1985–88, annual landings stabilized at approximately 10 million lb, then increased. In 1994, landings reached the highest level since 1946. The fishery for market squid was the largest and most profitable fishery in the Monterey Bay area in 1994. A total of 35.8 million lb of squid worth over $5.2 million was landed at the ports near the MBNMS during 1994. The ports of Moss Landing and Monterey accounted for 30% and 57% of this catch, respectively. Landings dropped drastically in 1995, again related to the El Niño years of 1992–93, followed by an upward trend until 1997. The El Niño conditions of 1997–98 caused a complete collapse of the squid fishery in Monterey for almost two years. Total squid landings have historically exhibited large fluctuations, rather than decreasing trends, despite this intense fishing pressure. However, the record harvests in the 1990s combined with the importance of squid as prey items for many species, caused some biologists to suggest a more precautionary approach to squid fishery management. The diet composition of Loligo opalescens in Monterey Bay (Karpov and Cailliet 1978) reflects a heavy dependence on omnivorous zooplankton.

Prey Categories	% in diet
Offshore omnivorous zooplankton	96.6
Herbivorous zooplankton	1.5
Deep epifauna	0.4
Squid	0.3
Near omnivorous zoo	0.3
Eulachon	0.2
Shallow sm. epifauna	0.2

Pacific Herring (*Clupea pallasii*)

Diet Composition of herring (Functional group composites of the mean proportions among years for each taxonomic group; from APEX-SEA data provided by M. Sturdevant (NMFS Alaska Fisheries Science Center)

Prey categories	% diet
Herbivorous zooplankton	59.2
Omnivorous zooplankton	32.6
Shallow small epifauna	8.2

Coho Salmon (*Oncorhynchus kisutch*)

Prey Species	**%**
Herring	30
Sand Lance	18
Pilchard	7
Anchovy	4
Rockfish	2
Other fish	9
Euphausiids	25
Squids	4
Other invertebrates	1

Pacific Sardine (*Sardinops sagax*)

Seabirds

Below is a list of krill-eating seabirds in the MBNMS. This list includes non-vagrant seabirds listed by Ainley and Terril (http://montereybay.nos.noaa.gov/sitechar/bird.html). We grouped the birds according to the relative quantity of krill they consume and the importance of krill to their diet. Krill is the principle prey of Cassin's Auklets year round. Other common seabird species in the MBNMS, such as Common Murre and Western Gull, consume krill as a major part of their diet on a seasonal basis (early spring). Still, other species are known to consume some krill, but not as a major part of their diet (e.g., Sooty Shearwater). The diet composition of many commonly occurring seabird species in the MBNMS is not well known, so the list of species consuming krill is probably larger than that summarized below. Notably, of the many piscivorous (fish-eating) seabirds that occur in the MBNMS, most feed on fish that feed on krill (e.g., rockfish, herring, hake, salmon). Therefore, practically all marine birds of the MBNMS either consume krill directly, or are part of the krill food web. It is also important to estimate the quantity of krill taken by migrant seabirds in MBNMS waters, but that is beyond the scope of this review.

Krill probably comprises >=50% diet:

- Cassin's Auklet (*Ptychoramphus aleuticus*) - all year

- Western Gull (*Larus occidentalis)* - spring only
- Common Murre (*Uria aalge*) - spring only

Krill may comprise 1% to 20% of the diet:

- Northern Fulmar (*Fulmarus glacialis*)
- Pink-footed Shearwater (*Puffinus creatopus)*
- Short-tailed Shearwater (*Puffinus tenuirostris)*
- Sooty Shearwater (*Puffinus griseus*)
- Ashy Storm-petrel (*Oceanodroma homochroa*)
- Black Storm-petrel (*Oceanodroma melania*)
- Fork-tailed Storm-petrel (*Oceanodroma furcata*)
- Leach's Storm-petrel *(Oceanodroma leucorhoa)*
- Cook's Petrel (*Pterodroma cooki)*
- Red Phalarope (*Phalaropus fulicaria*)
- Red-necked Phalarope (*Phalaropus lobatus*)
- Xantus' Murrelet (*Synthliboramphus hypoleucus*)

Other species that eat krill occasionally, or that consume fish that eat krill

- Black-vented Shearwater (*Puffinus opisthomelas)*
- Buller's Shearwater (*Puffinus bulleri)*
- Bonaparte's Gull (*Larus Philadelphia)*
- California Gull (*Larus californicus*)
- Franklin's Gull (*Larus pipixcan)*
- Glaucous-winged Gull (*Larus glaucescens)*
- Heermann's Gull (*Larus heermanni)*
- Mew Gull (*Larus canus)*
- Sabine's Gull (*Xema sabini)*
- Black-legged Kittiwake (*Rissa tridactyla)*

Arctic Tern (*Sterna paradisaea)*
Ancient Murrelet (*Synthliboramphus antiquus)*

Rockfish[5]

Krill are an important component in the diet of many rockfish found within the Monterey Bay National Marine Sanctuary. Included among these are species that have been identified by the Council as overfished such as widow rockfish and boccacio. On a local level, the species that have faced the greatest declines in mean length between 1959 and

[5] Adapted From: Trends in Fisheries and Fishery Resources Associated with the Monterey Bay National Marine Sanctuary From 1981–2000. R. Starr, J. Cope, L. Kerr . California Sea Grant College Program Publication No. T-046.

1994 are chilipepper (-27%), and yellowtail rockfish (-12%). Below are descriptions of the diet composition of these species and the corresponding prey requirements for the stocks within the Sanctuary. In addition, while the Council is familiar with the status of these stocks on a coast wide basis, a discussion of their respective significance to the local fishery may be useful and is therefore included.

Boccacio

Bocaccio is important in the commercial trawl and hook-and-line fisheries in Monterey Bay. They are also important in the sport catch, comprising 7% of the CPFV catch from 1959 to 1994. Current recreational limits set a bag limit of 2 bocaccio, with a minimum size of 10 in. Commercial landings at ports near the MBNMS averaged 2.55 million lb/yr from 1980–2000, with an unusually large catch in 1980 of 7.2 million lb from gill net catches in Half Moon Bay. Since 1982, bocaccio catches have consistently declined each year to just over 26,000 lb in 2000, primarily due to severe limitations on allowable catch. Stock assessment models show that bocaccio spawning stocks are severely depleted. Recruitment levels for bocaccio are highly variable, but have generally dropped as spawning stocks have declined. Stock assessments suggest that bocaccio abundance is 2% that of estimated 1970 levels, which is thought to have been an anomalously high abundance year for bocaccio. In 1999, the first strong recruitment episode since 1984 was seen and it is hoped this will start to rebuild the already depleted Central California populations. The diet composition for boccacio is xxx. Krill requirements for the stock xxx.

Chilipepper *(Sebastes goodei)*

Chilipepper are a very important component of the commercial trawl and sport fisheries in Central California. Commercial landings at ports near the MBNMS regularly fluctuated around an average of about 3 million lb/yr from 1980–98, but a sharp decline in catches followed in 1999 and 2000. Abundance estimates from catch data, age composition data, and length data all indicate that the stock size of chilipepper is increasing. Historical fluctuations of chilipepper catches have been mainly caused by environmental changes and/or effort switches over to salmon, but the current extreme decline in catches can be attributed to the close association chilipepper have with bocaccio. Because bocaccio and chilipepper schools are often mixed, and bocaccio quotas are very small, chilipepper landings have dropped as fishers try to avoid catching bocaccio. Diet composition, prey requirements.

Widow Rockfish (*Sebastes entomelas*)

Widow rockfish are the third most frequently caught scorpaenid in California commercial fisheries, with landings less than that of chilipepper and thornyheads. They are also a significant component of the sport landings. Commercial landings at ports near the MBNMS averaged 1.3 million lb/yr from 1981–2000. Widow rockfish landings peaked in 1982 at 7.3 million lb/yr when the trawl fishery began targeting the species. Landings have been much lower since then because of decreased population sizes and increased regulations. The widow rockfish stock coastwide is estimated to be about 18% the biomass in 1980. This stock is overfished and is expected to take a long time to recover despite current low harvest levels, partly because recruitment has decreased. Since the mid-1970s, this species has shown a decline in both spawning output and biomass. Krill prey requirements, composition.

Yellowtail Rockfish (*Sebastes flavidus*)
Yellowtail rockfish are landed commercially in both the trawl and hook-and-line fisheries. They also make up a considerable component of sport landings. Coastwide, yellowtail rockfish landings increased from 2.6 million lb in 1967 to 21.2 million lb in 1983, then declined after trip limits were implemented. From 1990–99, coastwide landings averaged 13 million lb/yr. Because yellowtail rockfish are centered off Northern California and Oregon, landings of this species in the MBNMS contribute a small portion of California landings. Composition, requirements.

Threatened and Endangered Species

There are a number of species listed under the Endangered Species Act (1973) which feed directly on krill populations found within the waters of the MBNMS. These include four species of marine mammals and xxx species of seabirds. The marine mammal species are Blue whales (*Balaenoptera musculus*), Humpback whales (*Megaptera novaeangliae*), Sei whales (*Balaenoptera borealis*), and Fin whales (*Balaenoptera physalus*). Endangered seabird species include marbled and xantus murrelets.

The distribution of krill within a geographic location is essentially patchy by nature. Primarily determined by environmental or oceanic conditions, the patches can form dense swarms. These swarms can result in aggregations of marine mammal and bird species such as those listed above. Since commercial harvesting would need to take advantage of these same swarms the result would be direct competition between vessels and endangered species, a far from desirable scenario. Little evidence is available on possible impacts of such a scenario, but in the austral summer of 1997, warming ocean conditions resulted in a substantial drop in krill abundance in Antarctic waters. As a result, the chick mortality of penguin species which feed directly on krill swarms increased by as much as 50%. Commercial krill harvesting combined with the uncertain nature of oceanic regimes certainly has the potential to heavily reduce krill density within seasons in sanctuary waters.

A number of endangered or threatened marine mammal species listed are also the basis for a commercial whale watching industry based within the MBNMS. As the fishery would correspond to the times of peak whale abundance it could be expected that the fishery could interfere with not only the feeding behavior of the whales, but the whale watching industry, and tourism in general.

Ecotourism/Socio-economics

Wildlife viewing in general and whale watching in particular are critical components of the local tourism industry. A krill fishery would coincide with the times of peak whale abundance, competing with the whales for forage and with species of seabird that are seasonally reliant on the resource. Quantifying the socio-economic impacts of a krill fishery are speculative and there is a wide spectrum of potential harm. However, given the foundational nature of the resource it would be reasonable to assume significant impacts on the marine ecosystem and the associated tourism industry. As part of the Sanctuary's joint management plan review process, NOAA conducted a socio-economic study of the tourism industry of the area adjacent to the Monterey Bay, Gulf of the Farallones, and Cordell Bank National Marine Sanctuaries. This study used results from the National Survey on Recreation and the Environment. It presents the usage of the marine environment in the state of California. While usage is concentrated in the southern portion of the state, the numbers may provide a rough guide for the Sanctuary which represents approximately one fourth of the California coast.

Activity	By Place of Activity			By Place of Residence
	Participation Rate (%)	Number of Participants (millions)	Number of Days (millions)	Number of Participants (millions)
Beach Visitation	6.1	12.6	151.4	9.1
Visiting Watersides Besides Beaches	0.7	1.5	20.7	1.1
Swimming	4.1	8.4	94.6	6.1
Snorkeling	0.3	0.7	3.8	1.3
Scuba Diving	0.1	0.3	1.4	0.4
Surfing	0.5	1.1	22.6	0.7
Windsurfing	0.0	0.1		0.1
Fishing	1.3	2.7	20.3	2.5
Motorboating	0.8	1.5	11.6	1.5
Sailing	0.5	1.1	6.8	1.0
Personal Watercraft Use	0.3	0.7	2.9	0.7
Canoeing	0.1	0.2		0.2
Kayaking	0.2	0.4		0.5
Rowing	0.1	0.3		0.2
Water-skiing	0.1	0.3	3.3	0.2
Bird Watching	1.3	2.6	65.8	1.9
Viewing Other Wildlife	1.2	2.6	38.6	4.4
Viewing or Photographing Scenery	2.0	4.2	107.9	2.9
Hunting Waterfowl	0.1	0.1		0.1